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Creation of an automated system for adjusting the position of the laser radiation axis for the air communication channel

K.S. Nazarova[1✉], V.V. Davydov[1,2]

[1] Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia;

[2] The Bonch-Bruevich St. Petersburg State University of Telecommunications, St. Petersburg, Russia

✉ knazarova0@ya.ru

Abstract. A model of an optical system for adjusting the axis of laser radiation on a photodetector module in a plane perpendicular to laser radiation has been developed. The operation of the optical system for controlling the position of the laser radiation axis on the photosensitive layer of the photodetector is simulated. Experimental studies are presented on correcting the position of the plates relative to the direction of the laser radiation axis and the value of stresses to change their refractive indices. The technique for determining the optimal parameters of the plates in the developed optical system for various tasks has been confirmed. The laser axis is automatically corrected and the displacement can be observed in real time. This allows data from other devices to be analyzed to identify the cause of the displacement and take the necessary action. Obtaining information on changes in displacement is a new principle not available in previously developed systems.

Keywords: Optical system, semiconductor laser, laser radiation axis, quartz plates, refractive index, linear and quadratic approximations

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Разработка автоматической системы подстройки положения оси лазерного излучения для воздушного канала связи

К.С. Назарова[1,✉], В.В. Давыдов[1,2]

[1] Санкт-Петербургский Политехнический университет Петра Великого

Санкт-Петербург, Россия;

[2] Санкт-Петербургский государственный университет телекоммуникаций им. проф. М.А. Бонч-Бруевича, Санкт-Петербург, Россия

✉ knazarova0@ya.ru

Аннотация. Разработана модель оптической системы для юстировки оси лазерного излучения на модуле фотодетектора в плоскости, перпендикулярной лазерному излучению. Смоделирована работа оптической системы управления положением оси лазерного излучения на фоточувствительном слое фотодетектора. Представлены экспериментальные исследования по коррекции положения пластин относительно направления оси лазерного излучения и величины напряжений для изменения их показателей преломления. Подтверждена методика определения оптимальных параметров пластин в разработанной оптической системе для различных задач. Ось лазерного излучения автоматически корректируется, и можно наблюдать смещение в реальном времени. Это позволяет анализировать данные других устройств для выявления причин смещения и принятия необходимых мер. Получение информации об изменениях в смещении - новый принцип, недоступный в ранее разработанных системах.

Ключевые слова: оптическая система, полупроводниковый лазер, ось лазерного излучения, кварцевые пластины, показатель преломления, линейная и квадратичная аппроксимации

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Introduction

Currently, the volume of information that is transmitted via different communication lines is constantly increasing [1–6]. The optical network, especially in large cities, operates with high overload [7–9]. The use of various methods of transmitting information with an increase in traffic volumes does not solve this problem. It is required to lay new lines that can damage existing communications. If you lay new communication channels in underground utilities, then you need to change everything, which is very expensive and takes a lot of time. The laying of overhead communication lines with optical fiber between buildings is prohibited, as this creates many problems when the cable breaks, for example from strong wind, etc. One of the solutions to the problem is the use of aerial optical communication channels (laser radiation spreads between modules through the air at distances of no more than 200 meters in the city, in mountainous areas and the sea, these distances increase to 2,000 m or more). The use of radio communication systems when transmitting large amounts of information in the city between buildings is impractical (low transmission speed and a large amount of electromagnetic interference) [2, 3, 9, 10]. In the other two cases, radio communication competes with the aerial optical communication channel (AOCC).

One of the problems of such systems is the displacement of the axis of the laser radiation, which contains information, relative to the plane of the photodetector. A shift from the center of the photosensitive layer of the photodetector module leads to a decrease in the amplitude of the recorded signal, which can lead to loss of information. Some AOCC designs use a focusing lens [11–13]. This allows to focus the laser radiation on photosensitive layer. These systems are often used in digital fiber optic communication lines (FOCL) [14–16]. Due to the reflections of the laser beam, information is distorted, especially when the axis of the laser radiation is shifted to the edge of the lens. The laser beam has a size. When it collides with the edge of the plate, diffraction occurs. Bit errors occur and the information cannot be recovered. Therefore, the development of an automatic system for the position of the laser radiation axis without the use of additional focusing elements in the receiving module is extremely relevant for the developing direction of aerial optical communication channels. Our goal is to develop a new automatic system to control the position of the laser axis.

Design of the aerial optical communication channel and the system of automatic adjustment of the axis of laser radiation

An analysis of the methods used to construct the position of the axis of laser radiation and the photodetector module in AOCC using the movement of a laser or photodetector, or mirrors, or lenses, allowed us to offer a new optical system of automatic adjustment. Fig. 1 shows the design of an aerial optical communication channel developed by us with a new auto-tuning module.

The adjustment of the position of the laser radiation axis is carried out according to the maximum amplitude of the current of the recorded optical signal on the photodetector module *6*. In the case of a laser radiation axis from the center of the photodetector module *6*, an error signal is

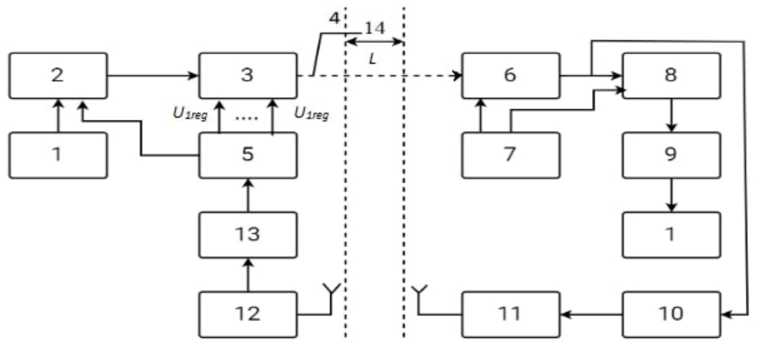

Fig. 1. Block diagram of an aerial optical communication channel: server *1*, laser transmitting module with electrooptical modulator *2*, automatic system for adjusting the position of the laser radiation axis *3*, laser radiation *4*, multifunctional power supply *5*, photodetector module *6*, photodetector power supply *7*, analog-digital converter (ADC) *8*, processing device *9*, current meter *10*, data processing and transmission device *11*, radio receiving device *12*, information processing and control device *13*, airspace *14*, *L* is the airspace length, U_{1reg} is the applied voltage

generated in the device *13*, which is transmitted using a radio channel to the building where the transmitting laser module *2* is located. A fundamentally new element in this design is an automatic optical system developed by me to adjust the position of the laser beam axis. Fig. *2* shows the design developed by us, one of two parts of the automatic system for aligning the position of the laser axis *3* for the AOCC under study (Fig. 1).

Fig. 2 shows the geometric position of the variation of the laser axis in the oX plane. To change the position of the laser radiation axis in the *oY* plane, such a part of the optical system design as shown in Fig. 2 is used, Only the quartz plates *2* (Fig. 2) will be oriented to the plane of incidence of laser radiation along the *oZ* axis at a different angle.

In order to implement the process of controlling the position of the laser radiation axis using the optical structure *3* we developed (Fig. 1), it is necessary that radiation with a plane-parallel front should arrive at the end of the plates. For this, the laser transmitting module *2* uses built-in optics (a macro lens with a short focal length). The macro lens is placed at the end of the laser resonator, so that the laser beam is placed in its focus.

The position of the laser beam axis is controlled by applying voltage to the ends of the plates *1*. Under the action of voltage, the refractive index *n* of quartz or other material from which the plate is made changes. The position of the laser radiation axis is shifted by the separation of Δl_x

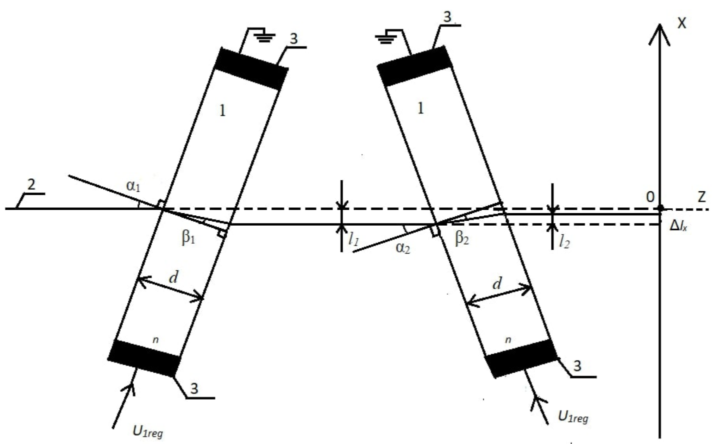

Fig. 2. Block diagram of part of automatic system for adjusting the position of the laser radiation axis along the *X* coordinate in a plane perpendicular to *oZ*: quartz plate *1*, laser radiation *2*, copper plate *3*

and Δl_y in a given plane. To determine the values of Δl_x and Δl_y it is necessary to derive mathematical relations from the change of n. Taking into account the semetricality of the arrangement of the plates relative to each other, the formula for calculating Δl_x or Δl_y will be the same (the difference will be only in the angles of inclination of the plates α.

Calculation of the displacement of the laser radiation axis and investigation of the operation of the automatic adjustment scheme

Based on the presented design of the optical system (Fig. 2), a calculation was performed to determine the offset of the radiation axis Δl_x in the *oX* plane.

$$\Delta l_x = l_1 - l_2, \tag{1}$$

$$l_1 = d(\sin(\alpha_1) - \frac{\frac{\sin(\alpha_1) * n}{n_0} * \cos(\alpha_1)}{\sqrt{1 - (\frac{\sin(\alpha_1) * n}{n_0})^2}}), \tag{2}$$

$$l_2 = d(\sin(\alpha_2) - \frac{\frac{\sin(\alpha_2) * n}{n_0} * \cos(\alpha_2)}{\sqrt{1 - (\frac{\sin(\alpha_2) * n}{n_0})^2}}). \tag{3}$$

Eqs. (2) and (3) with angles α_3 and α*4* only will be used to calculate Δl_y. The main parameter that is used to control the value of Δl_x is n. As an example, Fig. 3 shows the results of these studies with a detailed emphasis on the value of λ = 1550 nm at a temperature of $T \approx 294$ K.

a) *b*) *c*)

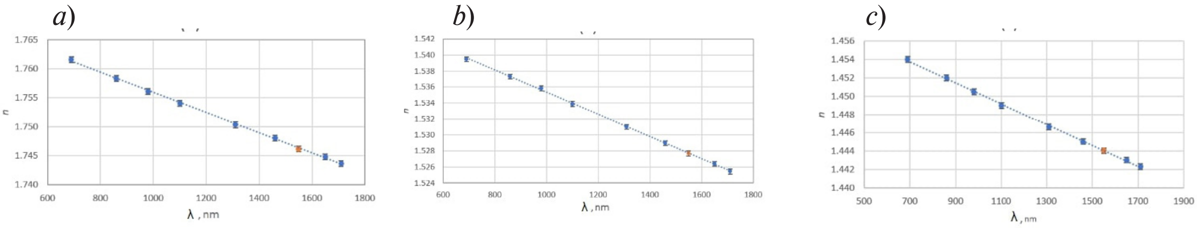

Fig. 3. Experimental dependence of the change in the refractive index n on λ. Graphs (*a*), (*b*) and (*c*) correspond to the following material: sapphire, quartz, and KU-1 glass

To determine the optimal position of the plates to the optical axis of the laser transmitting module, the optimal value of the angle α was determined for three materials that are supposed to be used for the manufacture of plates (quartz, glass KU-1 and sapphire). The dependences of Δl_x or Δl_y were differentiated by the angles of an and equated to zero. For all three materials (the refractive index was used for λ = 1550 nm at a temperature $T \approx 294$ K), the value of the optimal angles was about 52 degrees. This angle is at the point with the maximum steepness of the graph slope. Here the system's sensitivity to displacement is higher. Determination of the optimal angle is necessary to ensure high sensitivity of the system to changes in the position of the axis of laser radiation relative to the center of the photosensitive layer of the receiving module *6* (Fig. 1). Fig. 4 shows as an example the results of a study of the effect of changes in the angle of inclination α on the displacement Δl_x.

The analysis of the obtained results showed that the most optimal is the placement of deflecting plates *1* (Fig. 2) at an angle α ≈ 52°. This optimal value of the angle α within ±30 minutes corresponds to all three materials (quartz, glass KU-1 and sapphire). Plates with d = 4 cm were used in the studies.

a) *b*)

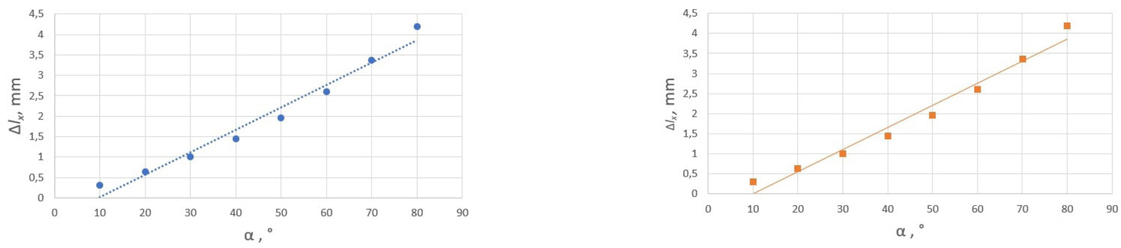

Fig. 4. Calculation of change in displacement of laser radiation axis from inclination angle of plates for various refractive indices of quartz (measured using a refractometer (*a*), linear approximation from tabular values when determining *n* for λ = 1550 nm (*b*))

To determine the possibility of adjusting the position of the laser radiation axis, the change in Δl_x from the change in the value of the refractive indices n of three materials was investigated. Fig. 5 shows the results of these studies for the case α = 52°, *d* = 4 cm.

a) *b*) *c*)

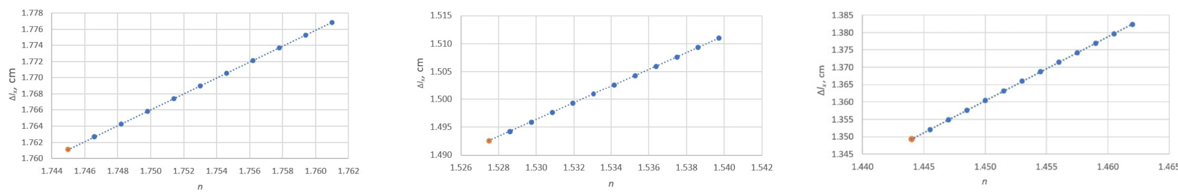

Fig. 5. Dependence of change in Δl_x on the index of refraction. Graphs (*a*), (*b*) and (*c*) correspond to sapphire, quartz and glass KU-1

The studies have shown that there is no big difference between quartz and sapphire in the characteristics of laser radiation position adjustment. In some cases of increasing the value of d and changing the optimum angle α, it is more appropriate to make plates from KU-1 glass. Advantages will be sapphire in the cost of plates, as well as this material is easier to process and polish. Sapphire should be preferred for use in different regions of the world. Quartz is a glass with a crystal lattice in the far zone. A pattern forms on its surface, especially after polishing, in wet and frosty weather conditions. Laser radiation is scattered and information is lost. It is possible to make a protective system with temperature stabilization (this will increase the cost and size of the structure). But it is more reasonable to use sapphire for all three reasons discussed, as well as a slight advantage in characteristics (Fig. 2). The conducted studies allowed us to establish that the range of variation of the optimal values of the angle α is from 35 to 65 degrees for different values of *d*. It is more appropriate to use a plate up to 100 mm thick. It should also be noted that an increase in the value of d leads to a slight increase in the constant voltage U_{gov}, which must be applied to the plates to change *n*. In experiments, the U_{gov} values changed to 42.8 V.

Conclusion

The results obtained confirm the possibility of using an automatic system developed by me to adjust the position of the laser radiation axis on the plane of the photodetector module in FOCL. Depending on the limitations on the size of the optical system (the *d* value is no more than 15 cm), it is possible to provide a maximum range of adjustment of the position of the laser axis in the range ±13.5 mm. With an increase in the size of the deflecting plates and, accordingly, the U_{gov} values, the values of Δl_x or Δl_y change.

Due to the reflection, which does not follow from mathematical calculations. This fact must be taken into account when developing such systems in the case of transmitting an optical signal over FOCL over long distances. With an increase in L, in order to ensure stable FOCL operation, it is necessary to increase the setting range of Δl_x.

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THE AUTHORS

NAZAROVA Kseniya S.
Knazarova0@ya.ru
ORCID: 0009-0004-4496-1505

DAVYDOV Vadim V.
davydov_vadim66@mail.ru
ORCID: 0000-0001-9530-4805

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